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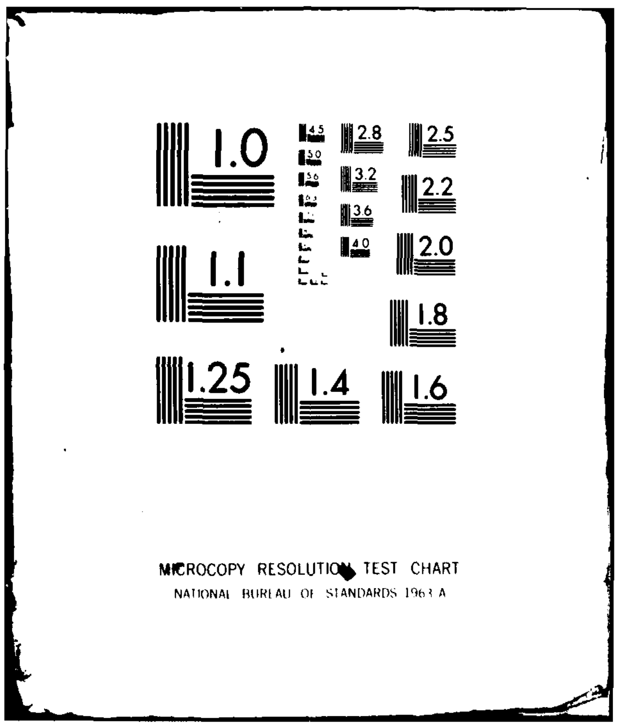
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REPORT NO. NADC-80078-60



# VALIDATION OF HEAT FLUX FOR STANDARD QUARTZ LAMP TESTER AND CALIBRATION OF NCTRF'S HEAT FLUX TRANSDUCER



J. R. Piergallini
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974



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Prepared for
NAVY CLOTHING AND TEXTILE RESEARCH FACILITY
21 Strathmore Road
Natick, Massachusetts 01760

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The objective was to verify calibration data of the Standard Quartz Lamp Tester used in Military Specification MIL-C-29143 for testing of the "Reflectivity after Abrasion" of aluminized fabrics for the Navy Clothing and Textile Research Facility (NCTRF). A reduced heat flux was recommended by the Aircraft Ground Fire Suppression and Rescue Office in their report, "Aircraft Firefighter's Protective Proximity Clothing" dated August 1975. The report concluded that the heat flux should be

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reduced to 1.9 cal/cm$^2$ sec for specification testing of aluminized fabric in order to be in agreement with reported findings. The 1.9 cal/cm$^2$ sec was found to be the average maximum heat flux from the side and in close proximity to a fuel fire. Verification by NAVAIRDEVCEN was required to certify that the changes to be recommended to the current specification were correct.

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## PROCEDURE AND APPARATUS

The procedure consists of verifying the NCTRF Heat Flux Transducer output voltage when exposed to specific voltages of 80, 82, 100, 110 and 119 volts on the NCTRF Quartz Lamp Tester. This tester contains five 9 in. GE 500T3-125 volt quartz infrared lamps placed horizontally and parallel to each other behind a cutout in a masonite board with a magnetically secured fabric sample test holder. Initially, the NCTRF transducer, a Medtherm Corporation Model No. 64-20-20, Serial No. 1122 Radiometer, was positioned behind the fabric test holder which is 1.125 in (28.575 mm) from the front surface of the quartz infrared lamps. Exposures were conducted at the specified voltages in accordance with the following test protocol:

Quartz Infrared Lamp-voltage off,

Shutter in,

Record after 60 seconds,

Shutter out,

Quartz Infrared Lamp-voltage on,

Record after 60 seconds,

Repeat test protocol.

This test procedure was repeated for the NAVAIRDEVCEN Heat Flux Transducer, a Hy-Cal Engineering Water Cooled Asymptotic Calorimeter Model No. C-1301-A-15-072, Serial No. 48817 at 80, 100 and 120 volts. Each heat flux transducer was centered horizontally and with a vertical distance of 80 mm from the center of the thermal sensing area of the radiometer to the base of the Quartz Lamp Tester. In the setup of the NCTRF heat flux transducer, this positioning required that a shim of 8.5 mm be placed beneath the existing transducer holder. The transducers were operated with cool water running through their outer jackets.

In addition to the heat flux transducer evaluation, a measurement of the infrared quartz lamp temperature was made using a Pyro Micro-Optical Pyrometer, Instrument Serial No. M-5120 in order to confirm NCTRF's temperature measurement at 80 volts. Also the calibration curve of the NAVAIRDEVCEN transducer was checked at 795 degrees C by placing it within the cavity of a High Temperature Infrared Radiation Reference Source (Barnes Engineering Company). Voltage to the Quartz Lamp Tester was supplied by a NAVAIRDEVCEN Variac rated at 250 VAC and 50 amps. A circuit breaker mounted on the Variac was used to switch the power to the lamps "on" and "off". Two shutters were used because of the differences in the test set-up with and without the magnetic fabric sample test holder. With the test holder and heat flux transducers at 1.125 in (28.575 mm) level, a Transite shutter with a thickness of 0.275 in (6.985 mm) was used to shield the radiometer during the quartz lamp cool down. Without the test holder and heat flux transducer at 1.0 in (25.4 mm) level, an asbestos shutter with a thickness of 0.0625 in (1.5785 mm) was used.

The instrumentation system consists of a Hewlett Packard Model 3490A Digital Voltmeter with a Hewlett Packard Model 3489A Data Punch for recording

the heat flux transducer outputs. An additional Hewlett Packard Model 3490A Digital Voltmeter was used to monitor the specific voltage set on the Quartz Lamp Tester. This voltage was maintained within $\pm$ 0.2 volts of the prescribed setting and in most instances within $\pm$ 0.1 volts.

## EXPERIMENTAL RESULTS

Table I illustrates the millivolt output of the NCTRF's transducer when exposed to input voltages of 80, 82, 90, 100, 110 and 119 volts on the NCTRF Quartz Lamp Tester at the 1.125 in (28.575 mm) level. Readings at each voltage are recorded alternately with and without the input voltage of the quartz lamps at 60 sec intervals as described in the test protocol. Interpreting the data is accomplished by subtracting the zero reading from the next subsequent reading which is taken with the quartz lamp on. In table I this provides 11 data points for each voltage level. The first data point is discarded and the following ten are used to calculate the ($\bar{X}$) mean (arithmetic average) of the accumulated data, the (S) standard deviation (a measure of dispersion around the mean), the (E) percent error which is the standard deviation divided by the mean and (H) heat flux in cal/cm$^2$ sec.

Table II shows the millivolt output of the NAVAIRDEVCEN transducer when exposed to input voltages of 80, 100 and 120 volts at the 1.125 in (28.575 mm) level. Table II is similar to table I with five data points instead of 11 and with two runs. In table II, the first two data points are discarded and the remaining three are used to calculate $\bar{X}$, S, E and H. The results of the two runs are averaged (av H) to provide the heat flux output curve vs the quartz lamp input voltage.

Table III illustrates the millivolt output of the NCTRF's transducer when exposed to input voltages of 80, 82, 90, 100, 110 and 119 volts at the 1.0 in (25.4 mm) level. Data in table III are analyzed identical to the data in table II.

Additional experimental data obtained in order to substantiate NCTRF's voltage settings on the Quartz Lamp Tester and the Hy-Cal calibration curve for the NAVAIRDEVCEN transducer include: (1) The reading of the optical pyrometer which indicated 1485 degrees C (2705 degrees F) when measuring the infrared quartz lamp temperature with the input voltage set at 80 volts, (2) the measurement of the Barnes Black Body Radiation Source cone with the optical pyrometer which indicated 795 degrees C (1463 degrees F) with the source set at 800 degrees C (1472 degrees F) and (3) the average millivolt output of the NAVAIRDEVCEN radiometer when exposed to the Barnes Radiation Source at 795 degrees C (1463 degrees F) was 4.251 millivolts.

## TABLE I

### NCTRF HEAT FLUX TRANSDUCER OUTPUT VOLTAGE AT 1.125 IN (28.575 mm) LEVEL VS INPUT VOLTAGE TO QUARTZ LAMP TESTER

| MILLIVOLT OUTPUT OF TRANSDUCER | VOLTAGE on QUARTZ LAMP TESTER | | | | | |
|---|---|---|---|---|---|---|
| | 80 | 82 | 90 | 100 | 110 | 119 |
| a | 0.012 * | 0.017 * | 0.037 * | 0.007 * | 0.010 * | 0.011 * |
| b | 2.231 * | 2.367 * | 2.998 * | 3.434 * | 4.087 * | 4.689 * |
| a | 0.021 | 0.026 | 0.055 | 0.025 | 0.031 | 0.036 |
| b | 2.385 | 2.517 | 3.037 | 3.571 | 4.228 | 4.856 |
| a | 0.031 | 0.037 | 0.068 | 0.043 | 0.054 | 0.061 |
| b | 2.408 | 2.523 | 3.049 | 3.599 | 4.263 | 4.904 |
| a | 0.043 | 0.045 | 0.074 | 0.056 | 0.069 | 0.080 |
| b | 2.418 | 2.547 | 3.050 | 3.625 | 4.302 | 4.946 |
| a | 0.047 | 0.051 | 0.082 | 0.058 | 0.081 | 0.092 |
| b | 2.426 | 2.572 | 3.033 | 3.649 | 4.320 | 4.975 |
| a | 0.053 | 0.055 | 0.085 | 0.074 | 0.091 | 0.095 |
| b | 2.441 | 2.549 | 3.045 | 3.665 | 4.332 | 4.970 |
| a | 0.054 | 0.061 | 0.087 | 0.083 | 0.089 | 0.106 |
| b | 2.462 | 2.543 | 3.063 | 3.650 | 4.355 | 4.989 |
| a | 0.054 | 0.060 | 0.092 | 0.087 | 0.104 | 0.112 |
| b | 2.451 | 2.560 | 3.070 | 3.683 | 4.347 | 5.004 |
| a | 0.057 | 0.064 | 0.088 | 0.083 | 0.109 | 0.112 |
| b | 2.450 | 2.566 | 3.052 | 3.677 | 4.341 | 5.003 |
| a | 0.059 | 0.067 | 0.096 | 0.088 | 0.108 | 0.118 |
| b | 2.447 | 2.578 | 3.057 | 3.666 | 4.354 | 5.018 |
| a | 0.059 | 0.078 | 0.083 | 0.092 | 0.109 | 0.127 |
| b | 2.444 | 2.571 | 3.048 | 3.663 | 4.356 | 5.029 |
| $\bar{X}$ | 2.385 | 2.498 | 2.969 | 3.576 | 4.235 | 4.876 |
| S | 0.012 | 0.012 | 0.011 | 0.017 | 0.020 | 0.026 |
| E | 0.5% | 0.5% | 0.4% | 0.5% | 0.5% | 0.5% |
| H | 1.465 | 1.535 | 1.830 | 2.209 | 2.621 | 3.022 |

Where

$\bar{X}$ = mean in millivolts
and S = standard deviation
E = % error
H = Heat Flux in cal/cm$^2$ sec
a = Zero reading with lamp off
b = uncorrected reading with lamp on
b-a = reading for one data point in millivolts
* = readings omitted in calculations

TABLE II

NAVAIRDEVCEN HEAT FLUX TRANSDUCER OUTPUT VOLTAGE AT 1.125 IN (28.575 mm) LEVEL VS INPUT VOLTAGE TO QUARTZ LAMP TESTER

| RUN NO. 1 | | VOLTAGE on QUARTZ LAMP TESTER 80 | 100 | 120 |
|---|---|---|---|---|
| MILLIVOLT OUTPUT OF TRANSDUCER | a | 0.003 * | 0.015 * | 0.005 * |
| | b | 3.504 * | 5.137 * | 6.886 * |
| | a | 0.017 * | 0.035 * | 0.031 * |
| | b | 3.708 * | 5.404 * | 7.181 * |
| | a | 0.035 | 0.056 | 0.067 |
| | b | 3.740 | 5.459 | 7.235 |
| | a | 0.048 | 0.078 | 0.093 |
| | b | 3.740 | 5.451 | 7.243 |
| | a | 0.057 | 0.089 | 0.115 |
| | b | 3.745 | 5.455 | 7.275 |
| | $\bar{X}$ | 3.695 | 5.381 | 7.159 |
| | S | 0.009 | 0.020 | 0.009 |
| | E | 0.2% | 0.4% | 0.1% |
| | H | 1.530 | 2.264 | 3.039 |
| RUN NO. 2 | | VOLTAGE on QUARTZ LAMP TESTER 80 | 100 | 120 |
| MILLIVOLT OUTPUT OF TRANSDUCER | a | 0.003 * | 0.030 * | 0.071 * |
| | b | 3.467 * | 5.143 * | 6.973 * |
| | a | 0.017 * | 0.043 * | 0.083 * |
| | b | 3.684 * | 5.397 * | 7.196 * |
| | a | 0.035 | 0.065 | 0.102 |
| | b | 3.734 | 5.427 | 7.258 |
| | a | 0.048 | 0.082 | 0.125 |
| | b | 3.749 | 5.442 | 7.254 |
| | a | 0.056 | 0.089 | 0.137 |
| | b | 3.752 | 5.460 | 7.256 |
| | $\bar{X}$ | 3.699 | 5.364 | 7.135 |
| | S | 0.003 | 0.006 | 0.019 |
| | E | 0.1% | 0.1% | 0.3% |
| | H | 1.532 | 2.257 | 3.028 |
| | av H | 1.531 | 2.261 | 3.034 |

NOTE: SEE LEGEND IN TABLE I.

TABLE II

NCTRF HEAT FLUX TRANSDUCER OUTPUT VOLTAGE AT 1.0 IN (25.4 mm) LEVEL VS INPUT VOLTAGE TO QUARTZ LAMP TESTER

| | | VOLTAGE on QUARTZ LAMP TESTER | | | | | |
|---|---|---|---|---|---|---|---|
| | | 80 | 82 | 90 | 100 | 110 | 119 |
| MILLIVOLT OUTPUT of TRANSDUCER | a | 0.003 * | 0.018 * | 0.015 * | 0.015 * | 0.012 * | 0.033 * |
| | b | 2.380 * | 2.553 * | 3.014 * | 3.629 * | 4.275 * | 4.941 * |
| | a | 0.035 * | 0.059 * | 0.060 * | 0.074 * | 0.084 * | 0.126 * |
| | b | 2.570 * | 2.704 * | 3.181 * | 3.818 * | 4.495 * | 5.173 * |
| | a | 0.061 | 0.087 | 0.083 | 0.118 | 0.140 | 0.170 |
| | b | 2.605 | 2.734 | 3.231 | 3.860 | 4.534 | 5.231 |
| | a | 0.081 | 0.102 | 0.105 | 0.133 | 0.153 | 0.198 |
| | b | 2.610 | 2.727 | 3.232 | 3.873 | 4.557 | 5.268 |
| | a | 0.087 | 0.113 | 0.109 | 0.141 | 0.178 | 0.213 |
| | b | 2.618 | 2.737 | 3.236 | 3.885 | 4.577 | 5.280 |
| | $\bar{X}$ | 2.535 | 2.632 | 3.134 | 3.742 | 4.399 | 5.066 |
| | S | 0.008 | 0.013 | 0.012 | 0.002 | 0.007 | 0.005 |
| | E | 0.3% | 0.5% | 0.4% | 0.1% | 0.2% | 0.1% |
| | H | 1.558 | 1.619 | 1.933 | 2.313 | 2.723 | 3.140 |

NOTE: SEE LEGEND IN TABLE I.

## DISCUSSION AND CONCLUSION

The equation for the lines given in the graphs of the certificates of calibration for each radiometer must be derived:

1) NCTRF Transducer Serial No. 1122

$$X = \frac{14.2\ (y - 0.042)}{6.5} \qquad \text{Eq. (1)}$$

2) NAVAIRDEVCEN Transducer Serial No. 48817

$$X = \frac{12.0\ (y - 0.180)}{8.4} \qquad \text{Eq. (2)}$$

where X = heat flux in Btu/ft$^2$sec
and y = transducer output in millivolts.

From table I it can be seen that the average millivolt output of the transducer at 80 volts is 2.385 mv and this reading can be expressed in cal/cm$^2$ sec by using equation 1 in conjunction with the appropriate conversion/correction factors. For example:

$$X = \left( \frac{14.2\ (2.385 - 0.042}{6.5} \ X \ 0.271 \right) \div 0.948$$

$$= 1.465 \text{ cal/cm}^2 \text{ sec}$$

where 0.271 is the constant to convert Btu/ft$^2$to cal/cm$^2$ and 0.948 is the absorptivity of the NCTRF transducer. Similarly from table II and equation 2

$$X = \left( \frac{12.0\ (3.695 - 0.180)}{8.4} \ X \ 0.271 \right) \div 0.890$$

$$= 1.530 \text{ cal/cm}^2 \text{ sec}$$

where 0.890 is the absorptivity of the NAVAIRDEVCEN transducer.

As a check on the accuracy of the NAVAIRDEVCEN transducer, a reading of 4.251 mv was recorded when the Black Body Radiation Source was at 795 degrees C. Using equation 2, the heat flux can be found from the millivolt output of the transducer:

$$X = \left( \frac{12.0\ (4.251 - 0.180)}{8.4} \ X \ 0.271 \right) \div 0.89$$

$$= 1.772 \text{ cal/cm}^2 \text{ sec}$$

Correspondly, the 795 degrees C temperature of the radiation source can be converted into a heat flux measurement by the Total Hemispherical Radiation (J) of

a Black Body Radiator formula:

$$J = \sigma (T_R^4 - T_A^4) \quad \text{Eq. (3)}$$

where

$$\sigma = 1.364 \times 10^{-12} \text{ cal/cm}^2 \text{ sec } {}^\circ K^4$$

and $T_R$ = absolute temperature of the radiator

$T_A$ = absolute temperature at ambient

Using equation 3:

$$J = 1.364 \times 10^{-12} \left((795 + 273)^4 - (18 + 273)^4\right)$$
$$= 1.765 \text{ cal/cm}^2 \text{ sec}$$

This showed that the NAVAIRDEVCEN transducer was accurate to within 0.4 percent of reading at this point which is considerably better than the limits of experimental error associated with this type of measurement.

The heat flux data vs the quartz lamp voltage settings for exposures at 1.125 in (28.575 mm) from tables I and II is plotted in figure 1 which represents a linear least squares solution or the best fit to a straight line for the data points in each table. The equations for the lines plotted in figure 1 follow:

1) NCTRF Transducer Serial No. 1122 (+ data points)

$$y = 0.0396x - 1.725 \quad \text{Eq. (4)}$$

2) NAVAIRDEVCEN Transducer Serial No. 48817 (o data points)

$$y = 0.0376x - 1.481 \quad \text{Eq. (5)}$$

where y = heat flux in $\text{cal/cm}^2$ sec
and x = quartz lamp voltage in volts.

Similarly the heat flux data vs the quartz lamp voltage settings for exposures at 1.0 in (25.4mm) from table III for the NCTRF transducer are plotted in figure 2 and follow the equation:

$$y = 0.0403x - 1.686 \quad \text{Eq. (6)}$$

where y = heat flux in $\text{cal/cm}^2$ sec
and x = quartz lamp voltage in volts.

Equations 4 and 5 define the millivolt outputs at the quartz lamp voltage settings for each transducer. Using these equations together with equation 6, a mathematical solution to provide the heat flux vs quartz lamp voltage curve for the NAVAIRDEVCEN transducer at the 1.0 in (25.4 mm) exposure level is

possible. The equation for this plot follows:

$$y = 0.0381x - 1.442 \qquad \text{Eq. (7)}$$

where y = heat flux in cal/$cm^2$ sec
and x = quartz lamp voltage in volts.

Through the use of tables I and II, the calibration curve for the NCTRF transducer in terms of millivolt output vs heat flux in cal/$cm^2$ sec can be generated in the form of figure 3. This was accomplished by using computer techniques which are described in the next paragraph.

From table I an equation for a curve can be established in terms of millivolt output of the transducer vs the heat flux as the quartz lamp voltage varies from 80 to 120 volts. Next, an equation for a curve can be generated in terms of millivolt output of the NCTRF transducer vs the NAVAIRDEVCEN heat flux data in table II for the same 80 to 120 volt exposure. This provides the following equation which describes figure 3 and the calibration curve for the NCTRF Heat Flux Transducer Serial No. 1122:

$$y = 1.6890x - 0.219 \qquad \text{Eq. (8)}$$

where y = transducer output in millivolts
and x = heat flux in cal/$cm^2$ sec.

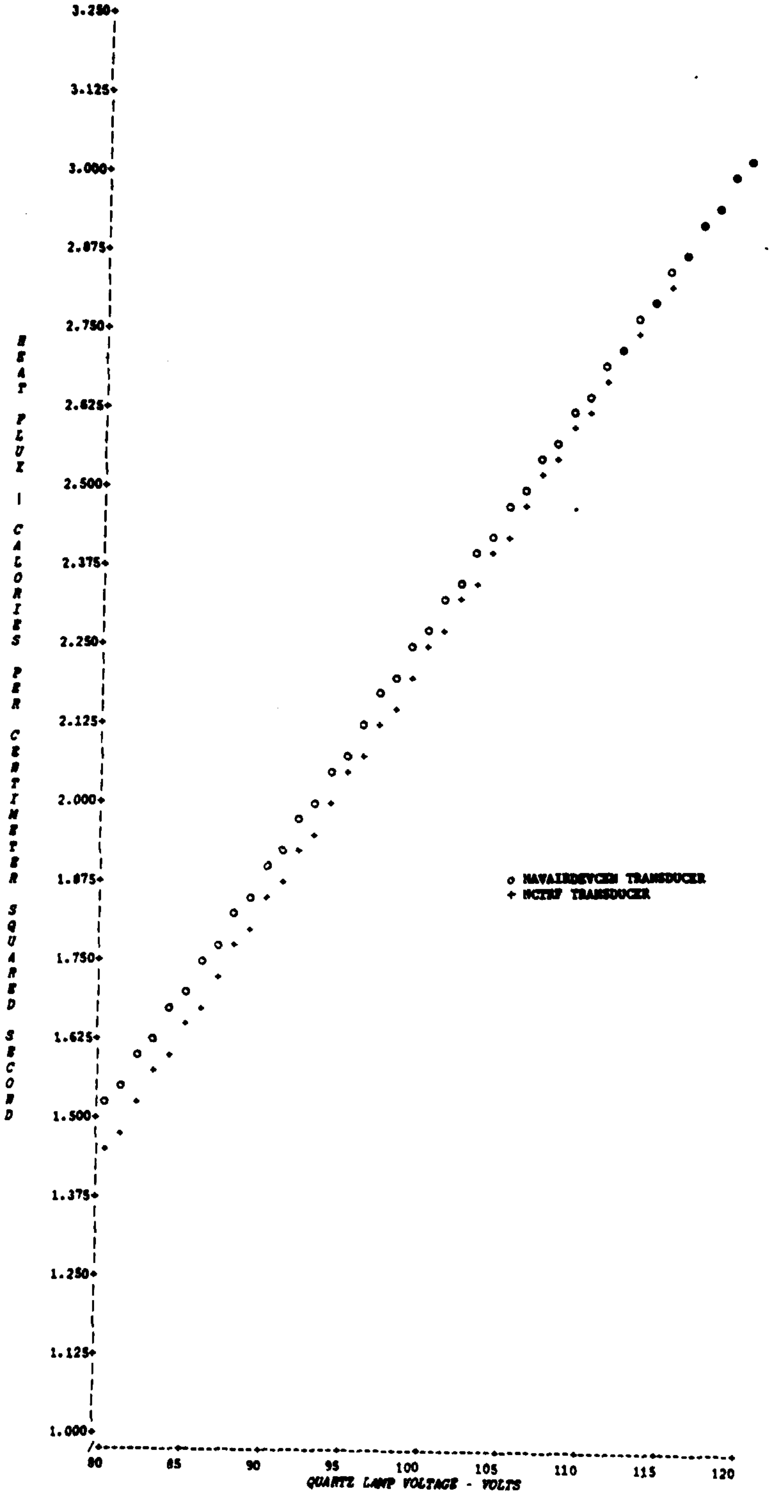


FIGURE 1 - HEAT FLUX VS QUARTZ LAMP VOLTAGE FOR NCTRF AND NAVAIRDEVCEN TRANSDUCERS AT 1.125 in (28.575 mm) LEVEL

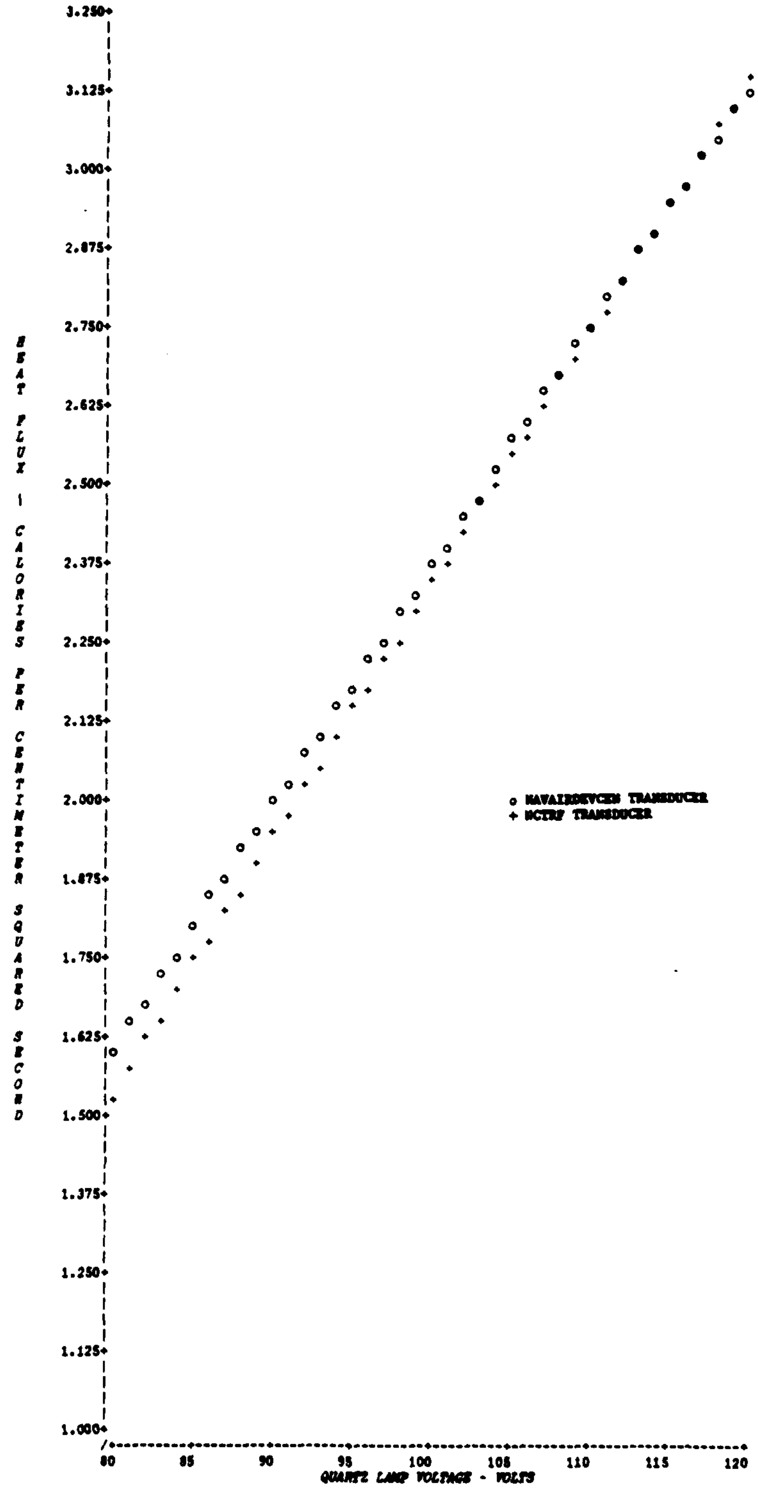


FIGURE 2 - HEAT FLUX VS QUARTZ LAMP VOLTAGE FOR NCTRF AND NAVAIRDEVCEN TRANSDUCERS AT 1.0 in (25.4 mm) LEVEL

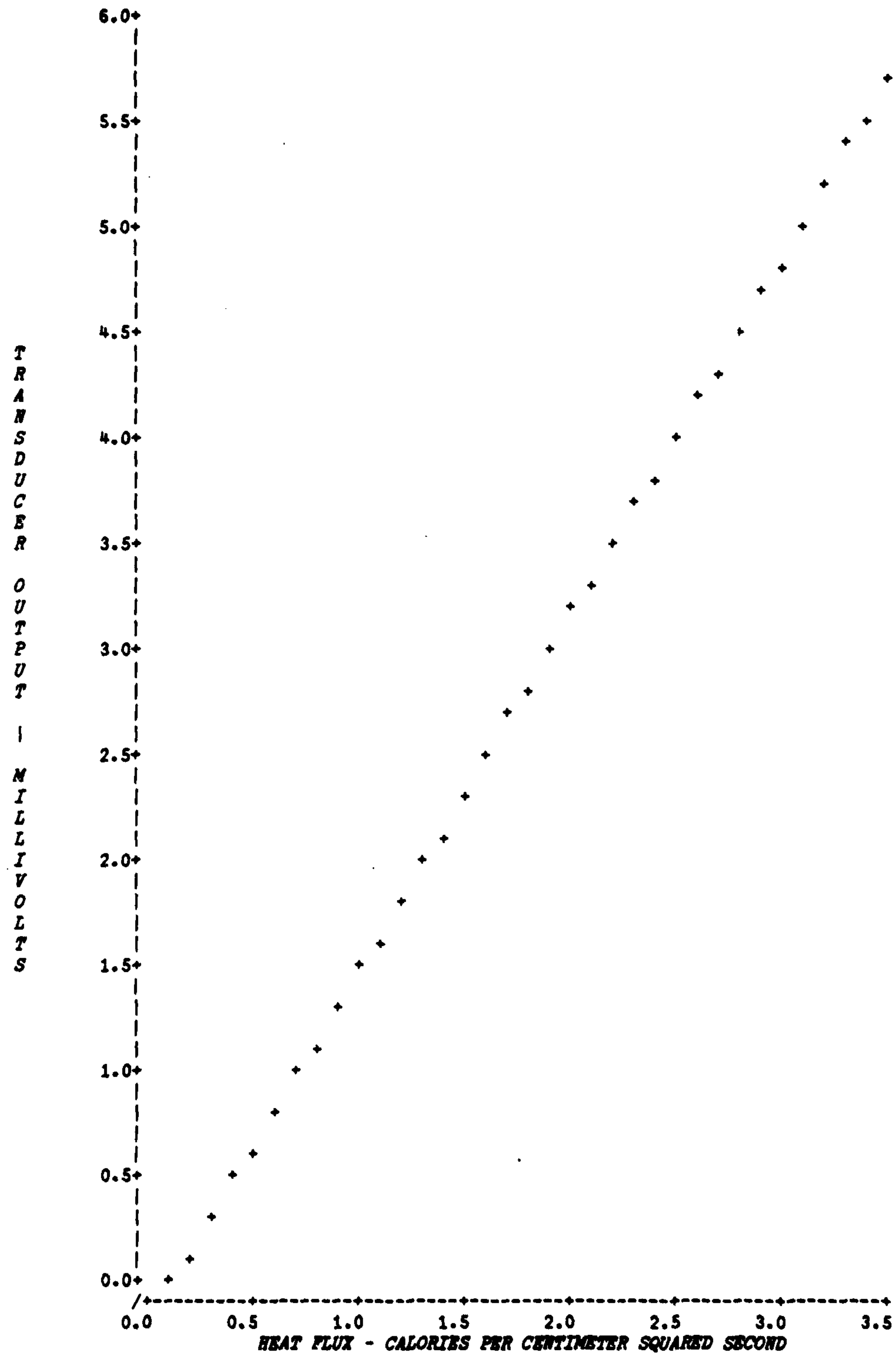


FIGURE 3 - CALIBRATION CURVE FOR NCTRF'S HEAT FLUX TRANSDUCER

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